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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
February 1946 as
Restricted Bulletin L5K02

AERODYNAMIC CHARACTERISTICS OF FOUR NACA AIRFOIL SECTIONS DESIGNED FOR HELICOPTER ROTOR BLADES

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WASHINGTON

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RESTRICTED BULLETIN

AERODYNAMIC CHARACTERISTICS OF FOUR NACA AIRFOIL SECTIONS DESIGNED FOR HELICOPTER ROTOR BLADES

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SUMMARY

Four NACA airfoil sections, the NACA 7-H-12, 8-H-12, 9-H-12, and 10-H-12, suitable for use as rotor-blade sections for helicopters and other rotary-wing aircraft have been derived and tested. These airfoil sections have comparatively low drags in the range of low and moderate lifts and small pitching moments that are nearly constant up to maximum lift. The undesirable adverse changes in aerodynamic characteristics at higher lifts and the undue sensitivity to roughness, which were found for the airfoil sections reported in NACA CB No. 3I13, are minimized for the airfoil sections presented. A comparison of calculated profile-drag losses for a rotor successively incorporating the NACA 3-H-13.5 (reported in NACA CB No. 3I13) and the 8-H-12 airfoil sections showed that the NACA 8-H-12 had smaller profile-drag losses in nearly every operating condition presented. From aerodynamic considerations, the NACA 8-H-12 and 9-H-12 airfoil sections appeared more promising for use as rotor-blade sections than any other airfoils thus far tested at the NACA laboratories.

INTRODUCTION

The desirable aerodynamic characteristics of airfoil sections suitable for use as rotor-blade sections are: (1) nearly zero pitching moments, (2) low drags throughout the range of low and moderate lifts, and (3) moderate drags at high lifts. With these characteristics in mind several rotor-blade sections were derived with special emphasis on obtaining high lift-drag ratios. These airfoils, data for which are presented in reference 1, had maximum lift-drag ratios nearly twice as large as those of the NACA 230-series airfoils at the same Reynolds number.

They showed, however, some undesirable characteristics: namely, sensitivity to roughness and abrupt adverse changes in drag, lift-curve slope, and pitching moment in the vicinity of the high-lift end of the range of low drags.

The purpose of the present work is to extend the previous investigation and to derive additional airfoil sections designed to minimize the undesirable characteristics of the previously tested airfoils. The tests of these additional airfoils were made in the Langley two-dimensional low-turbulence tunnel (LTT).

By the use of the procedure given in reference 2, profile-drag losses have been calculated for a typical helicopter rotor operating in various flight conditions and successively incorporating the airfoil sections developed in the present investigation. These calculations permit the evaluation of the relative profile-drag losses associated with the use of the various airfoil sections.

SYMBOLS

α_o	section angle of attack
c	chord
c_d	section drag coefficient
c_l	section lift coefficient
c_{l_i}	design section lift coefficient
$(c_l/c_d)_{max}$	maximum lift-drag ratio
$c_{m_{a.c.}}$	moment coefficient about aerodynamic center
$c_{m_{c/4}}$	moment coefficient about the quarter-chord point
hp	horsepower
H_o	free-stream total pressure
M_{cr}	critical Mach number

p local static pressure on airfoil surface

q_o free-stream dynamic pressure

R Reynolds number

S pressure coefficient $\left(\frac{H_o - p}{q_o}\right)$

t/c airfoil thickness ratio

x distance along chord from leading edge

y distance perpendicular to chord

μ tip-speed ratio $\left(V\frac{\cos \alpha}{\Omega R}\right)$

The following symbols are used only in tables VI, VII, and VIII:

V forward speed

W/S rotor disk loading, pounds per square foot

f parasite-drag area, square feet

$\lambda\Omega R$ speed of axial flow through rotor disk (positive upward)

Ω rotor angular velocity, radians per second

R rotor blade radius

α angle of attack of rotor disk

σ solidity; ratio of total blade area to swept-disk area

θ pitch angle of blade element, degrees

θ_1 difference between hub and tip pitch angles, degrees (positive when tip angle is greater)

DERIVATION AND TESTS

In the derivation of the four airfoil sections tested in this investigation several basic thickness distributions having a maximum thickness of 0.12c were employed. The NACA 7-H-12 airfoil section has an NACA 0012 thickness distribution, the NACA 8-H-12 and 9-H-12 airfoil sections have thickness distributions that have their minimum pressure at 0.3c at zero lift, and the NACA 10-H-12 airfoil section has a thickness distribution that has its minimum pressure at 0.5c at zero lift. The mean lines of these four airfoil sections were designed so that small pitching moments and extensive favorable pressure gradients along the lower surfaces were produced. In the designation of these airfoils the first number is a serial number, the H indicates that the airfoil has been designed for use on helicopters and other rotating-wing aircraft, and the last two digits designate the thickness in percent of the chord. Ordinates for these airfoil sections are given in tables I to IV.

The models, constructed of mahogany laminated in the chordwise direction, had a chord of 24 inches and a span of $35\frac{1}{2}$ inches. In preparation for the tests the surfaces of the models were sanded in a chordwise direction with No. 400 carborundum paper in order to obtain aerodynamically smooth surfaces. Each model was tested in the Langley two-dimensional low-turbulence tunnel. This wind tunnel has a closed throat with a rectangular test section 3 feet wide and $7\frac{1}{2}$ feet high and is designed to test models completely spanning the width of the tunnel in two-dimensional flow. The low-turbulence level amounts to only a few hundredths of 1 percent and is achieved by the large contraction ratio (approx. 20 to 1) and by the introduction of a number of fine-wire small-mesh turbulence-reducing screens in the widest part of the entrance cone. The maximum speed of this wind tunnel is approximately 155 miles per hour.

The lift and pitching moments were obtained from balance readings; the drags were obtained from measurements of pressures in the wake. The pressure-distribution measurements were obtained by the use of a static-pressure tube placed at convenient positions along the airfoil surface. The roughness, applied along the span to the leading edge of the models, consisted of a 1-inch-wide strip of carborundum-covered cellulose tape. This roughness was sufficient to cause transition virtually at the leading edge. Lift, drag, and pitching-moment data were obtained at Reynolds numbers of 1.8 and 2.6×10^6 for each of the models in the smooth and rough conditions. Pressure-distribution measurements were made for each airfoil at an angle of attack corresponding approximately to the design lift coefficient.

All pitching moments were obtained in the tunnel about the quarter-chord position and were transferred to the aerodynamic center. Only the pitching moments about the aerodynamic center are presented. The lift, drag, and pitching-moment data have been corrected for tunnel-wall interference by factors that include corrections due to the shape, size, and the effect upon the velocity measured by fixed static-pressure orifices in the tunnel walls of the airfoil model mounted in the tunnel. For the airfoils of the present report the corrections reduce to the following form, in which the primed quantities refer to the values measured in the tunnel:

NACA 7-H-12, 8-H-12, and 9-H-12 airfoil sections	NACA 10-H-12 airfoil section
$c_l = 0.977c_l'$	$c_l = 0.978c_l'$
$\alpha_o = 1.015\alpha_o'$	$\alpha_o = 1.015\alpha_o'$
$c_{m_{c/4}} = 0.992c_{m_{c/4}}'$	$c_{m_{c/4}} = 0.993c_{m_{c/4}}'$
$c_d = 0.992c_d'$	$c_d = 0.993c_d'$

RESULTS AND DISCUSSION

The results of the tests of the NACA 7-H-12, 8-H-12, 9-H-12, and 10-H-12 airfoil sections are presented in figures 1 to 4, respectively. Each figure is divided into two parts: the first part presents the lift, drag, and pitching-moment data and the second part presents the pressure distribution obtained at approximately the design lift coefficient.

All the pitching moments about the aerodynamic center for the airfoils of this report are essentially constant up to maximum lift and show no breaks in the curves as were shown for some of the airfoils of reference 1. The data show that the NACA 7-H-12 and 8-H-12 airfoil sections (figs. 1(a) and 2(a)) have pitching moments that are nearly zero throughout an extensive lift range. The NACA 9-H-12 and 10-H-12 airfoil sections (figs. 3(a) and 4(a)) have small negative pitching moments up to the stall. The addition of roughness on the leading edge of each of the airfoil sections has very little effect on the magnitude of the pitching moments except in the region of maximum lift.

A comparison of the maximum lifts of the airfoils of this investigation with those of the NACA 0012 and 23012 airfoil sections (1.36 at a Reynolds number of 2.5×10^6 for the NACA 0012 airfoil section and 1.6 at a Reynolds number of 3.0×10^6 for the NACA 23012 airfoil section) shows that the maximum lifts for the airfoils of the present report are slightly lower than for the NACA 0012 airfoil section and materially lower than for the NACA 23012 airfoil section at the same Reynolds number. The lift curves for the airfoil sections investigated herein, however, are more rounded near the peak, especially for the NACA 8-H-12 and 9-H-12 airfoils where high lifts are maintained over a considerable range of angles both in the smooth and rough conditions. In the rough condition the maximum lifts of each of the four airfoils reduce to essentially the same value (1.13). Data for other airfoil sections at approximately the same Reynolds number indicate a similar value of maximum lift for most airfoil sections with leading-edge roughness. There is no measurable change in lift due to roughness at the small angles of attack.

The minimum drags of the NACA 8-H-12, 9-H-12, and 10-H-12 airfoil sections correspond very closely to the minimum drags of airfoil sections for which the thickness distributions have their minimum pressure at 0.5c at zero lift. The aforementioned airfoils of the present report also show a definite range of lifts for low drags. For the NACA 7-H-12 airfoil section (having an NACA 0012 thickness distribution) the minimum drag is somewhat higher than for the other three airfoils but is less than that expected of the NACA 23012 or 0012 airfoil sections at the same Reynolds number.

The drags for each of the airfoils of the present report increase rapidly at high lifts, but this increase is much smaller than that of the NACA 3-H-13.5 airfoil section reported in reference 1. The addition of roughness on the leading edge results in an increase in drag, for the four airfoils, similar to that found for other airfoil sections.

A summary of the important characteristics of the NACA 7-H-12, 8-H-12, 9-H-12, and 10-H-12 airfoil sections is given in table V in which the aerodynamic characteristics are presented for a Reynolds number of 2.6×10^6. Data for the NACA 3-H-13.5 airfoil section, as obtained from table II and figure 8 of reference 1, have been included for comparison.

Although the flow conditions over an airfoil section mounted rigidly in the wind tunnel are different from those over a section of a rotor blade in operation, the section characteristics measured in the wind tunnel, particularly for low and moderate angles of attack, are not expected to be very different from those exhibited by the rotor-blade section. Because the greatest part of the profile-drag losses occurs while the blades are operating in the region of low to moderate angles of attack, less accuracy is required for calculations at the higher angles of attack. It is therefore concluded that relative merits of rotor-blade sections may be evaluated from airfoil section data. The relative merit of a particular airfoil section depends largely on the operating conditions and the design of the rotor. In reference 2 rotor characteristics and flight conditions that were believed typical were assumed, and weighting factors were obtained for each condition to permit the rotor-blade profile-drag loss to be calculated. Table VI presents these assumed rotor characteristics and flight conditions for the sample helicopter. By the use of the weighting factors the profile-drag losses were calculated for a rotor that successively incorporated the NACA 7-H-12, 8-H-12, 9-H-12, and 10-H-12 airfoil sections in the smooth and rough conditions. For comparison, calculations were also made of the rotor-blade profile-drag losses of a rotor incorporating an NACA 23012 airfoil section in the smooth condition. Drag data for each airfoil were incomplete at high angles of attack and a method given in reference 2 was used to extend these data. The rotor-blade profile-drag losses were calculated for several flight conditions and the results given in table VII show the effect of loading in hovering and in forward flight and the effect of tip-speed ratio.

A comparison of the values given in table VII for the smooth airfoil indicates that the NACA 8-H-12 and 9-H-12 airfoil sections have, in general, the least profile-drag losses for the flight conditions presented. For a particular disk loading or tip-speed ratio a choice of one of the other airfoil sections might be indicated. At very high pitch settings in hovering flight (condition 3) and the high tip-speed ratio ($\mu = 0.3$, condition 6) the NACA 23012 airfoil section has the least profile-drag losses. In these conditions, sections of the rotor are operating at high angles of attack where the NACA 23012 airfoil section has lower drags than the airfoils presented herein, which accounts for the lower profile-drag losses. For the airfoils of this report in the rough condition, the values of profile-drag loss differ very little. In either the smooth or rough surface condition, the airfoil sections having, in general, the least profile-drag losses for the operating conditions presented herein are the NACA 8-H-12 and 9-H-12 sections. Preference, however, would probably be given the NACA 8-H-12 airfoil section because it has a smaller pitching-moment coefficient about the aerodynamic center (0.005) than the NACA 9-H-12 airfoil section (-0.012).

In order to provide a comparison of the calculations of rotor-blade profile-drag loss given in this report with similar calculations for the most promising airfoil section of reference 1, data for the NACA 8-H-12 and 3-H-13.5 airfoil sections in the smooth condition are presented in table VIII. The values for the NACA 3-H-13.5 airfoil section were obtained from table I of reference 1. The NACA 3-H-13.5 airfoil section had the larger value of maximum lift-drag ratio (see table V), but the profile-drag losses for the NACA 8-H-12 airfoil section are less in every condition presented except for the disk loadings of 3.33 and 2.5 in hovering flight (conditions 2 and 4). The magnitude of the lift-drag ratio in itself therefore is not a reliable indication as to the relative merit of airfoil sections intended for use in rotor blades. The NACA 8-H-12 airfoil section shows a large reduction in profile-drag loss as compared with that of the NACA 3-H-13.5 airfoil section at the highest pitch setting in hovering flight (condition 3). Large reductions are also shown at the high disk loading in cruising flight (condition 8) and at high speed (condition 6). These reductions were made possible by the lower drags at the high angles of attack.

The weighting curves of reference 2 provide not only a means for the calculation of the rotor-blade profile-drag loss but also a direct indication as to the relative importance of regions of the drag of a rotor airfoil section. For the assumed conditions these weighting curves indicate that for hovering with a rotor-blade pitch angle of approximately 6° to 10° and for low forward speeds, the region of section drag coefficients corresponding to $c_l \doteq 0.2$ to 0.6 has the greatest effect upon the magnitude of the rotor profile-drag loss. For high disk loadings in hovering and low forward speeds and for high forward speeds at normal or high disk loadings, the same region of drags still has the greatest effect, but the drags at high lifts are also prominent in affecting the magnitude of the profile-drag loss.

CONCLUDING REMARKS

The NACA 7-H-12, 8-H-12, 9-H-12, and 10-H-12 airfoil sections, derived for use as rotor-blade sections of rotary-wing aircraft, have been tested in the Langley two-dimensional low-turbulence tunnel. These airfoil sections had comparatively low drags in the range of low and moderate lifts and nearly constant pitching moments up to maximum lift and the aerodynamic characteristics were not unduly sensitive to roughness. The NACA 8-H-12, 9-H-12, and 10-H-12 airfoil sections had a definite range of lifts for low drags and had minimum drags corresponding closely to the minimum drags of airfoil sections for which the thickness distributions have their minimum pressure at 0.5c at zero lift. From a comparison of the calculated profile-drag losses of a typical helicopter rotor successively incorporating the airfoils of this report, the NACA 8-H-12 and 9-H-12 airfoil sections had, in general, the least losses in the operating conditions presented. The NACA 8-H-12 airfoil section, having the smaller pitching moments, would probably receive preference as a rotor-blade section. Compared with the NACA 3-H-13.5 airfoil section reported in NACA CB No. 3I13, the NACA 8-H-12 airfoil showed smaller profile-drag losses in nearly every operating condition presented.

From aerodynamic considerations the NACA 8-H-12 and 9-H-12 airfoil sections appeared more promising for use as rotor-blade sections than any other airfoils thus far tested at the NACA laboratories.

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TABLE I.- ORDINATES FOR
NACA 7-H-12 AIRFOIL SECTION

[Stations and ordinates given in percent of airfoil chord]

Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.627	2.346	1.873	-1.232
1.802	3.464	3.198	-1.576
4.296	5.018	5.704	-1.952
6.853	6.127	8.147	-2.173
9.431	6.973	10.569	-2.323
14.608	8.138	15.392	-2.524
19.779	8.816	20.221	-2.652
24.932	9.143	25.068	-2.739
30.059	9.208	29.941	-2.796
40.237	8.737	39.763	-2.859
50.316	7.712	49.684	-2.858
60.315	6.326	59.685	-2.778
70.253	4.730	69.747	-2.580
80.154	3.043	79.846	-2.193
90.046	1.404	89.954	-1.490
95.003	.665	94.997	-.949
100.000	0	100.000	0

L.E. radius: 1.58
Slope of radius through L.E.: 0.443

TABLE II.- ORDINATES FOR
NACA 8-H-12 AIRFOIL SECTION

[Stations and ordinates given in percent of airfoil chord]

Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.147	1.229	.853	-.819
.358	1.520	1.142	-.946
.804	2.006	1.696	-1.128
1.980	2.941	3.020	-1.415
4.424	4.312	5.576	-1.736
6.914	5.380	8.086	-1.920
9.427	6.263	10.573	-2.059
14.497	7.626	15.503	-2.242
19.607	8.605	20.393	-2.351
24.754	9.243	25.246	-2.417
29.969	9.533	30.031	-2.455
35.174	9.432	34.826	-2.490
40.292	9.030	39.708	-2.494
45.360	8.420	44.640	-2.476
50.390	7.666	49.610	-2.436
55.387	6.795	54.613	-2.377
60.358	5.846	59.642	-2.290
65.311	4.850	64.689	-2.178
70.250	3.838	69.750	-2.034
75.184	2.838	74.816	-1.860
80.118	1.895	79.882	-1.645
85.060	1.046	84.940	-1.384
90.016	.343	89.984	-1.051
94.995	-.119	95.005	-.629
100.000	0	100.000	0

L.E. radius: 1.325
Slope of radius through L.E.: 0.344

TABLE III.- ORDINATES FOR
NACA 9-H-12 AIRFOIL SECTION

[Stations and ordinates given in percent of airfoil chord]

Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.117	1.238	.883	-.788
.323	1.537	1.177	-.907
.764	2.037	1.736	-1.073
1.933	3.003	3.067	-1.329
4.369	4.427	5.631	-1.598
6.857	5.540	8.143	-1.742
9.370	6.461	10.630	-1.843
14.443	7.890	15.557	-1.968
19.559	8.919	20.441	-2.029
24.714	9.599	25.286	-2.057
29.936	9.921	30.064	-2.067
35.150	9.845	34.850	-2.079
40.277	9.458	39.723	-2.066
45.353	8.859	44.647	-2.039
50.390	8.107	49.610	-1.995
55.393	7.232	54.607	-1.938
60.369	6.273	59.631	-1.861
65.324	5.261	64.676	-1.765
70.266	4.225	69.734	-1.645
75.200	3.194	74.800	-1.500
80.134	2.212	79.866	-1.326
85.073	1.314	84.927	-1.114
90.026	.550	89.974	-.844
95.000	.008	95.000	-.502
100.000	0	100.000	0

L.E. radius: 1.325
Slope of radius through L.E.: 0.378

TABLE IV.- ORDINATES FOR
NACA 10-H-12 AIRFOIL SECTION

[Stations and ordinates given in percent of airfoil chord]

Upper Surface		Lower Surface	
Station	Ordinate	Station	Ordinate
0	0	0	0
.234	1.062	.766	-.706
.451	1.319	1.049	-.817
.911	1.724	1.589	-.966
2.108	2.508	2.892	-1.158
4.551	3.720	5.449	-1.414
7.028	4.695	7.972	-1.579
9.521	5.523	10.479	-1.707
14.540	6.878	15.460	-1.878
19.588	7.929	20.412	-1.987
24.657	8.726	25.343	-2.064
29.743	9.315	30.257	-2.105
34.844	9.695	35.156	-2.125
39.963	9.860	40.037	-2.134
45.104	9.789	44.896	-2.107
50.310	9.420	49.690	-2.078
55.476	8.698	54.524	-2.084
60.518	7.736	59.482	-2.096
65.497	6.622	64.503	-2.084
70.433	5.405	69.567	-2.031
75.341	4.153	74.659	-1.927
80.236	2.908	79.764	-1.758
85.133	1.739	84.867	-1.511
90.048	.723	89.952	-1.169
94.999	-.002	95.001	-.714
100.000	0	100.000	0

L.E. radius: 1.000
Slope of radius through L.E.: 0.301

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TABLE V.- AIRFOIL SECTION CHARACTERISTICS

$\left[R = 2.6 \times 10^6\right]$

Section characteristics \ NACA airfoil section		7-H-12	8-H-12	9-H-12	10-H-12	3-H-13.5 (reference 1)
$(c_l/c_d)_{max}$		106	135	152	149	163
$c_{m_{a.c.}}$		------	0.005	-0.012	-0.022	0.003
$c_{d_{min}}$		0.0055	0.0046	0.0046	0.0043	0.0050
Low-drag range		------	0.25 to 0.91	0.39 to 0.93	0.30 to 0.76	0.38 to 0.88
$c_{l_{max}}$	Smooth	1.34	1.26	1.26	1.30	1.20
	Rough	1.10	1.13	1.12	1.14	--------
M_{cr} at c_{l_i}		0.601	0.569	0.569	0.619	0.56
c_{l_i} (approx.)		0.42	0.57	0.60	0.46	0.60
t/c at 0.25c		0.119	0.117	0.117	0.108	0.1208
a.c. position	x/c	0.250	0.278	0.267	0.261	0.250
	y/c	0.021	0.020	0.025	0.021	--------

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TABLE VI.- FLIGHT CONDITIONS AND ASSUMED CHARACTERISTICS OF THE SAMPLE HELICOPTER OF REFERENCE 2

[Rotor diam., 40 ft; tip speed, 400 fps; gross weight for W/S of 2.5, 3140 lbs]

Condition	μ	W/S	σ	θ_1	θ	λ	f
1	0	1.55	0.07	0	7	-------	15
2		3.33			13	-------	
3		5.42			19	-------	
4		2.5			10.3	-------	
5	0.2	2.5			9	-0.0385	
6	.3	2.5			11	-.0695	
7	.2	1.9			7	-.0319	
8	.2	3.1			11	-.0469	
9	.2	2.5	0.10		7	-.0350	
10	.3	2.5	.07	-8	[a]10.5	-.0680	
11	.3	2.5	.07	-8	[a]8.5	-.0435	[b]0

[a]Measured at 0.75 R.
[b]Rotor alone.

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TABLE VII.- COMPARISON OF ROTOR-BLADE PROFILE-DRAG LOSS FOR VARIOUS FLIGHT CONDITIONS OF THE SAMPLE HELICOPTER

Conditions (see table VI)			Rotor-blade profile-drag loss, hp									Remarks
			NACA airfoil section									
			7-H-12		8-H-12		9-H-12		10-H-12		23012	
			Smooth	Rough	Smooth	Rough	Smooth	Rough	Smooth	Rough	Smooth	
1	W/S = 1.55	μ = 0	17.2	30.7	14.4	32.3	17.3	30.1	13.4	31.9	20.1	Effect of loading (hovering flight)
2	3.33	0	25.9	33.7	18.5	39.0	17.2	38.2	17.8	41.5	24.1	
3	5.42	0	42.6	116.2	56.8	112.1	57.9	132.2	114.3	-----	42.6	
4	μ = 0	W/S = 2.5	22.0	31.9	16.3	35.3	15.4	33.8	14.0	35.9	21.7	Effect of tip-speed ratio
5	.2	2.5	24.8	37.4	21.2	41.4	20.0	39.3	23.6	41.7	25.7	
6	.3	2.5	42.3	73.4	36.7	65.7	37.9	66.1	40.3	52.0	31.0	
7	W/S = 1.9	μ = 0.2	22.0	34.8	17.5	37.7	19.4	35.5	17.6	37.9	23.5	Effect of loading (forward flight)
5	2.5	.2	24.8	37.4	21.2	41.4	20.0	39.3	23.6	41.7	25.7	
8	3.1	.2	30.6	58.0	28.6	57.3	28.8	59.4	39.5	45.9	29.2	

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TABLE VIII.- COMPARISON OF ROTOR-BLADE PROFILE-DRAG LOSS OF THE NACA 3-H-13.5 AND 8-H-12 AIRFOIL SECTIONS IN THE SMOOTH CONDITION FOR VARIOUS FLIGHT CONDITIONS OF THE SAMPLE HELICOPTER

	Conditions (see table VI)		Rotor-blade profile-drag loss, hp		Remarks
			NACA 3-H-13.5 (reference 1)	NACA 8-H-12	
1	$W/S = 1.55$	$\mu = 0$	16.0	14.4	Effect of loading (hovering flight)
2	3.33	0	14.5	18.5	
3	5.42	0	204.6	56.8	
4	$\mu = 0$	$W/S = 2.5$	14.2	16.3	Effect of tip-speed ratio
5	.2	2.5	23.2	21.2	
6	.3	2.5	54.5	36.7	
7	$W/S = 1.9$	$\mu = 0.2$	18.2	17.5	Effect of loading (forward flight)
5	2.5	.2	23.2	21.2	
8	3.1	.2	54.3	28.6	
5	$\sigma = 0.07$	$\mu = 0.2$	23.2	21.2	Effect of solidity
9	.10	.2	26.1	25.2	
6	$\theta_1 = 0^\circ$	$\mu = 0.3$	54.5	36.7	Effect of blade twist
10	-8°	.3	42.4	27.7	
10	$f = 15$	$\mu = 0.3$	42.4	27.7	Effect of power input
11	0	.3	35.9	27.4	

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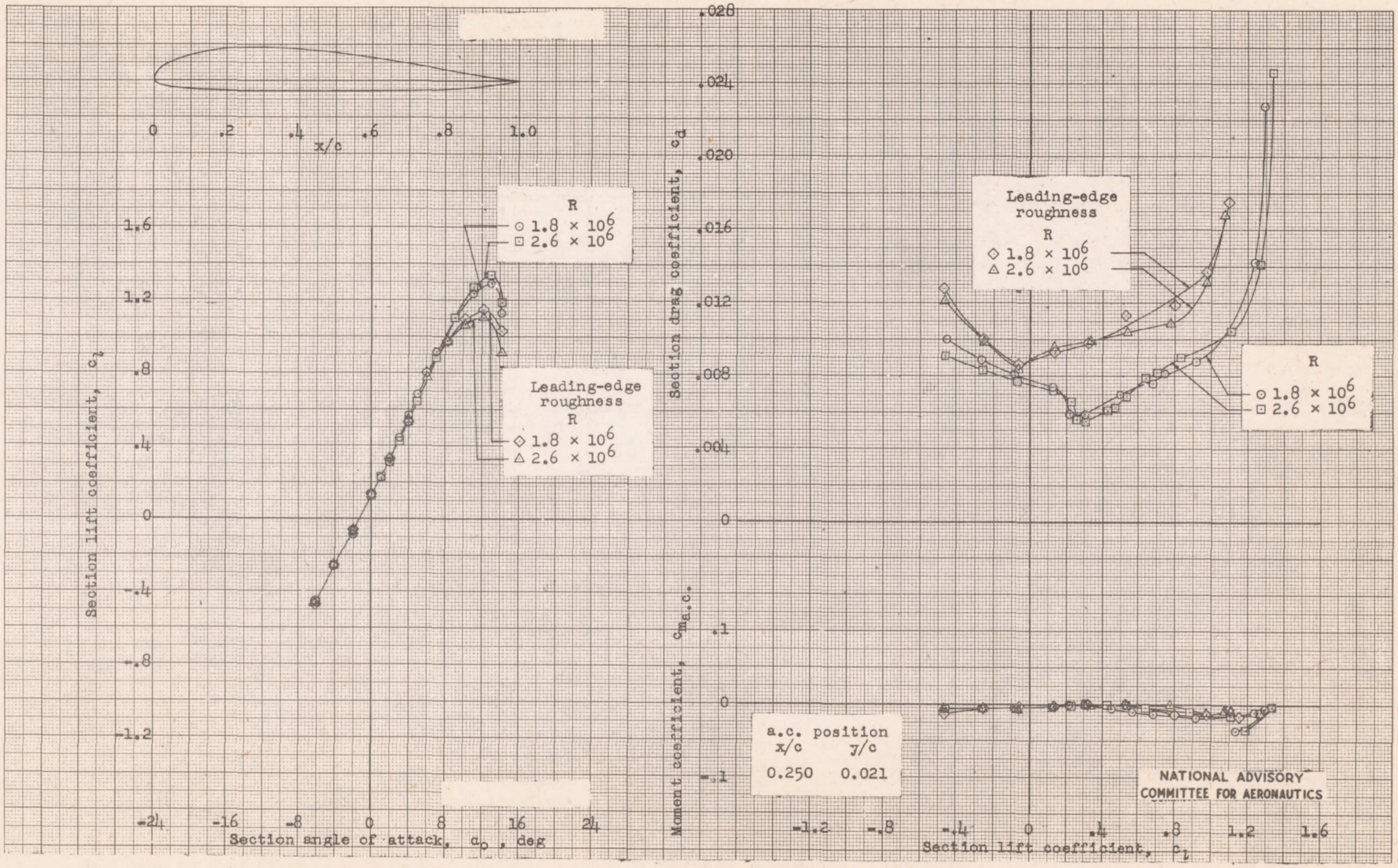
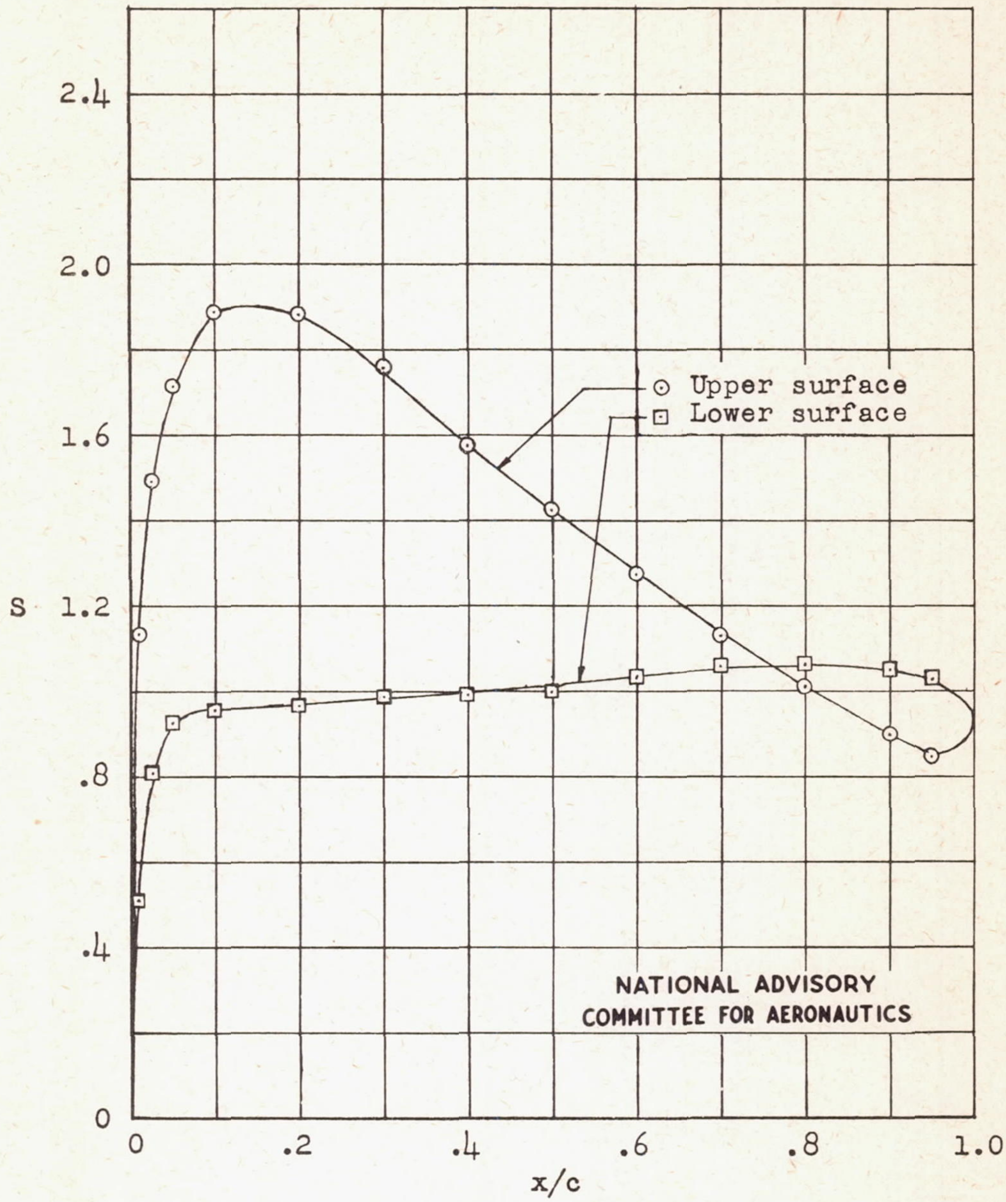


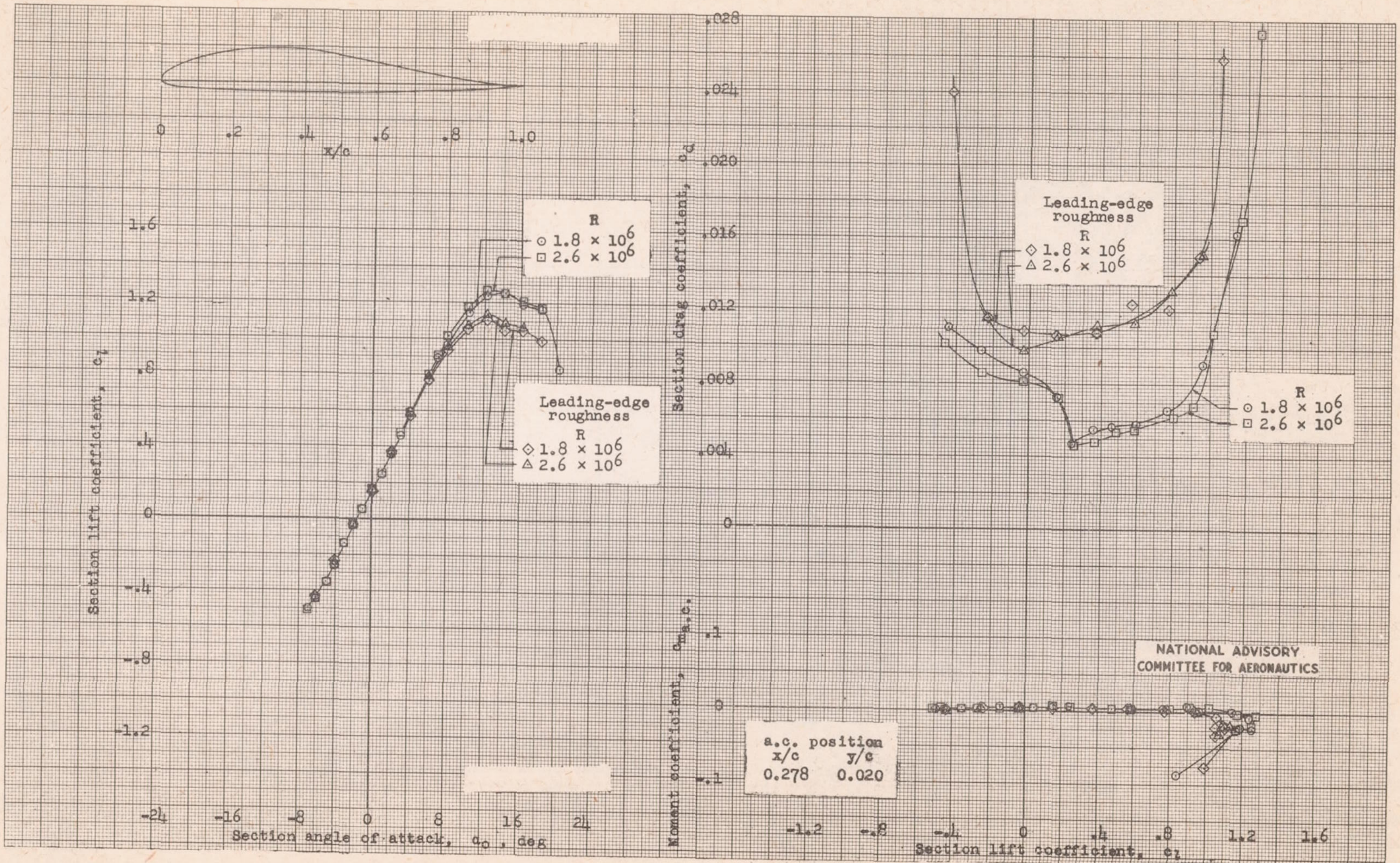
(a) Section lift, drag, and pitching-moment data

Figure 1.- Aerodynamic characteristics of the NACA 7-H-12 airfoil section, 24-inch chord; LTT tests 330, 334.



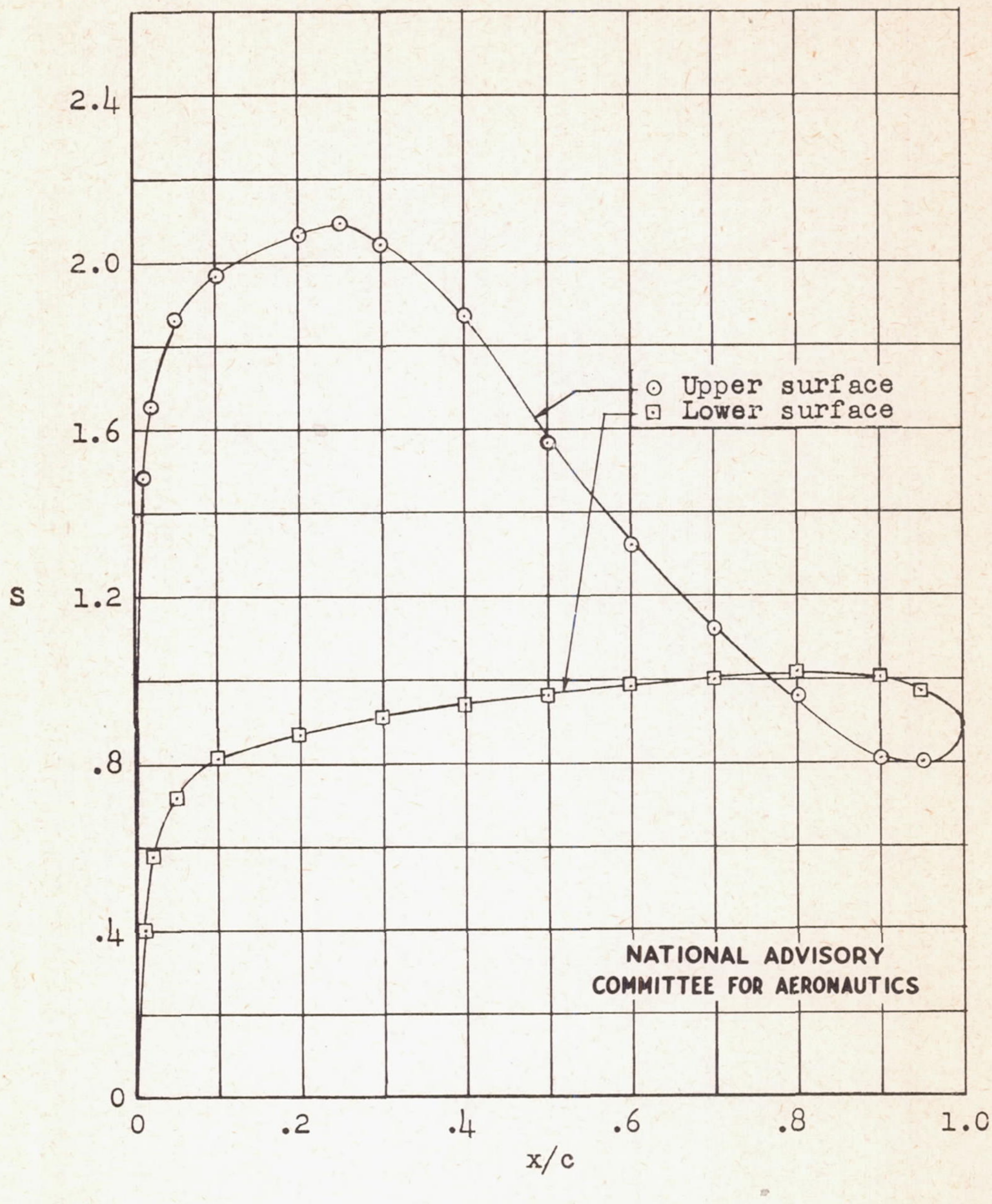
(b) Pressure distribution for design lift coefficient, $c_{l_i} = 0.42$; $R = 2.6 \times 10^6$.

Figure 1.- Concluded.



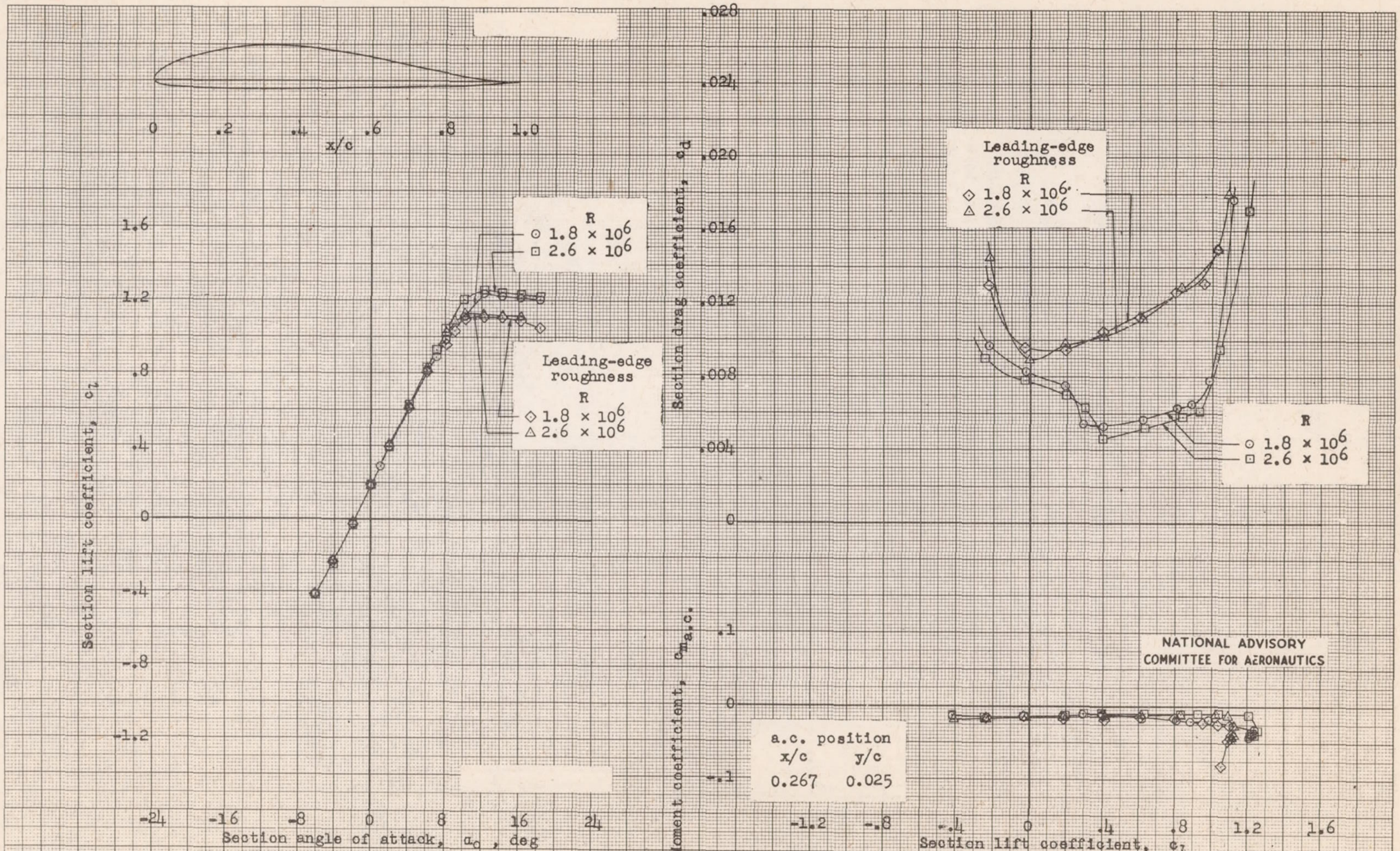
(a) Section lift, drag, and pitching-moment data

Figure 2.- Aerodynamic characteristics of the NACA 8-H-12 airfoil section, 24-inch chord; LTT test 350.



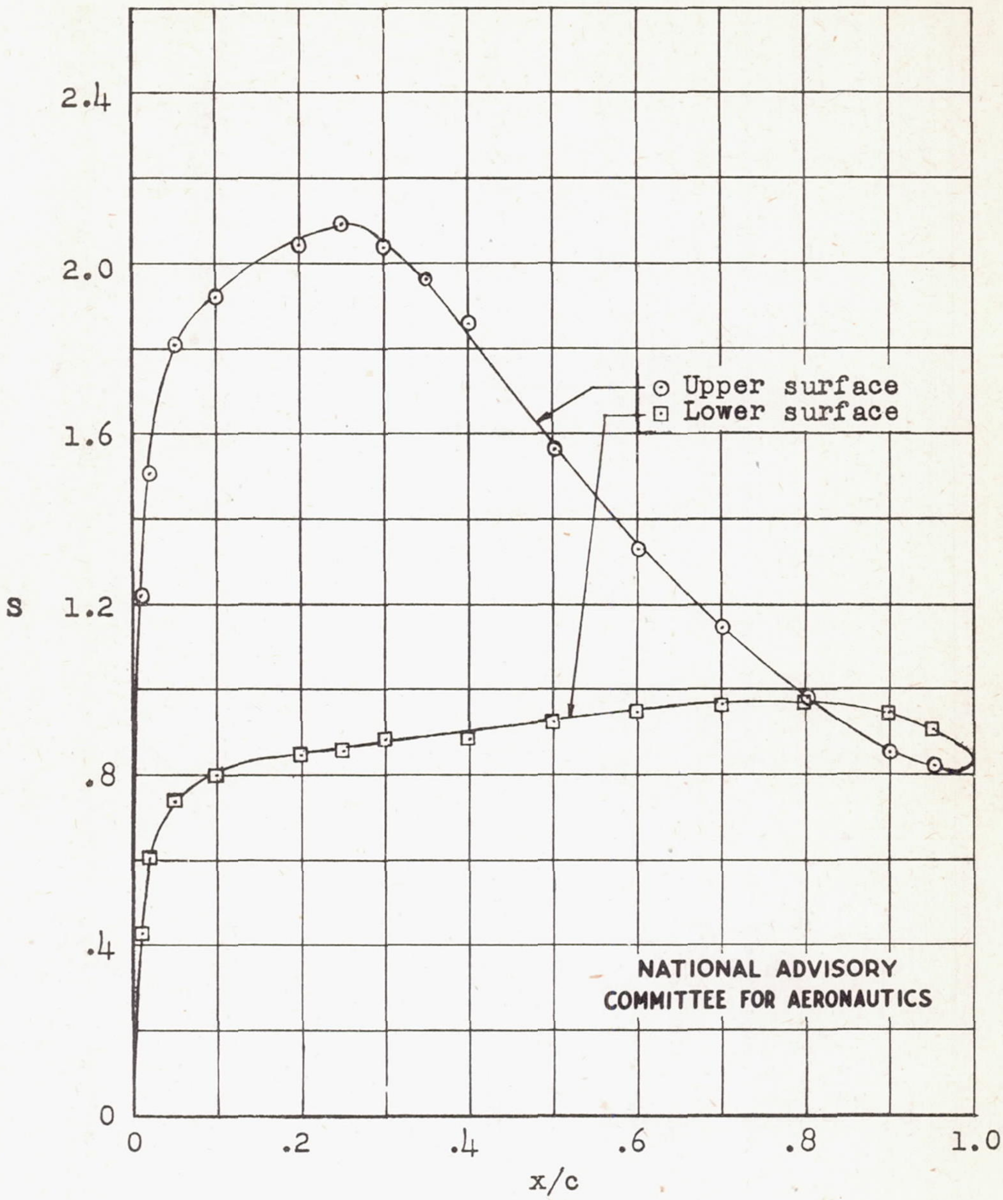
(b) Pressure distribution for design lift coefficient, $c_{l_i} = 0.57$; $R = 2.6 \times 10^6$.

Figure 2.- Concluded.



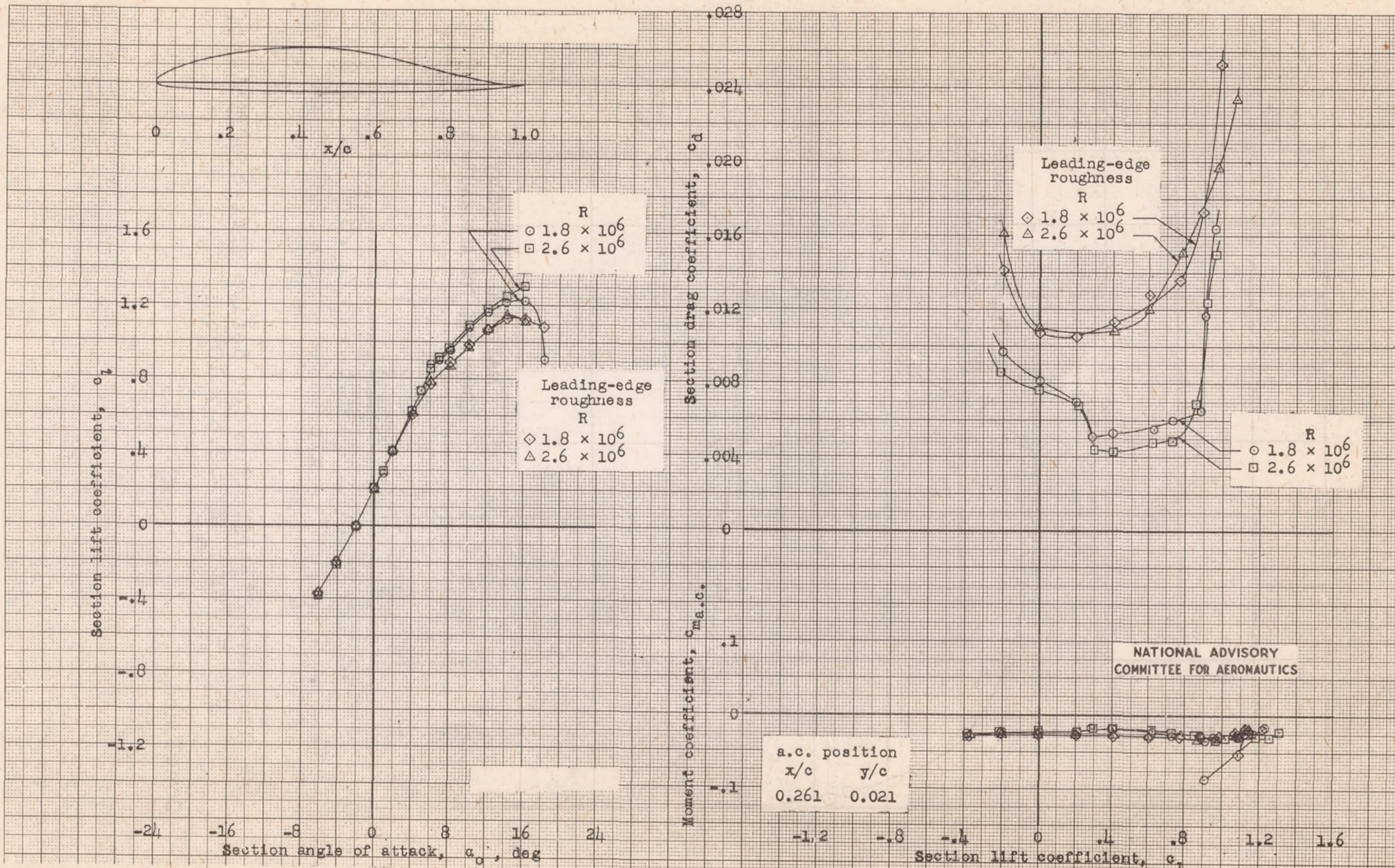
(a) Section lift, drag, and pitching-moment data

Figure 3.- Aerodynamic characteristics of the NACA 9-H-12 airfoil section, 24-inch chord; LTT test 336.



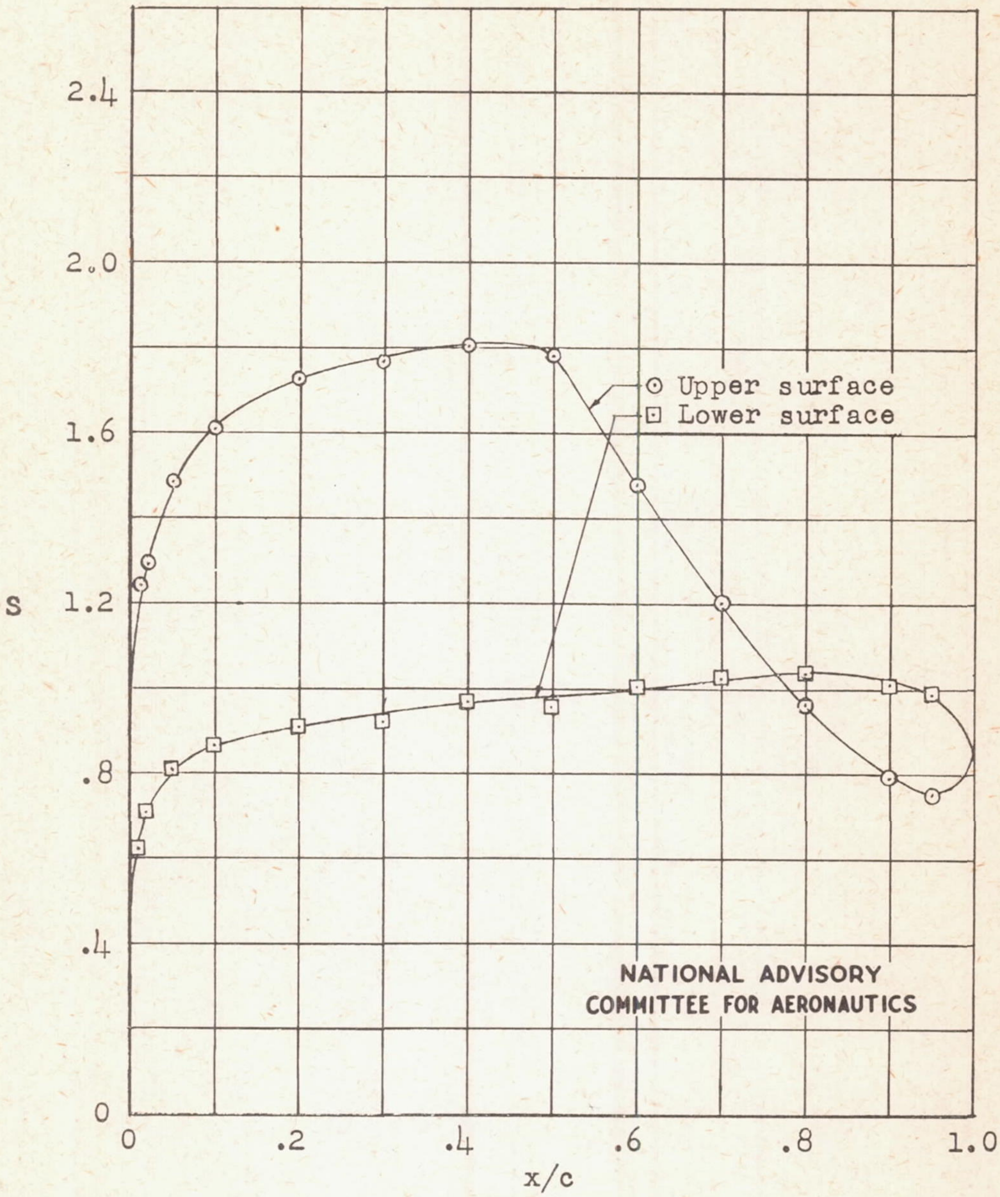
(b) Pressure distribution for design lift coefficient, $c_{l_i} = 0.60$; $R = 2.6 \times 10^6$.

Figure 3.- Concluded.



(a) Section lift, drag, and pitching-moment data

Figure 4.- Aerodynamic characteristics of the NACA 10-H-12 airfoil section, 24-inch chord; LTT test 336.



(b) Pressure distribution for design lift coefficient, $c_{l_i} = 0.46$; $R = 2.6 \times 10^6$.

Figure 4.- Concluded.